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TITLE: **Studying Upper-Limb Amputee Prosthesis Use to Inform Device Design**

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14. ABSTRACT  The proposed project investigates the nature of upper limb prosthesis use in everyday tasks through in-home and lab-based studies on upper-limb amputees and matched unimpaired subjects. During the past year we have established the experimental protocols, received IRB approval (from all institutes) and established the measurement equipment and lab setup that will be used in the study. This equipment has included a modified GoPro head-mounted camera and a Vicon 13-camera optical motion capture system, which was not part of original proposal. As part of the setup of the motion capture system we have also selected and developed upper body marker sets and post-processing pipelines that match standards in the field of biomechanics. This system and the associated pre and post processing techniques will provide much richer and more informative motion data than with video					
15. SUBJECT TERMS Upper Limb Prosthetics, Amputee, Assistive Technology, Motion Capture					
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## **1. INTRODUCTION**

The proposed project centers on investigating the nature of upper limb prosthesis use in everyday tasks through both an in-home and lab-based study on upper-limb amputees and age and gender-matched normal subjects. For the in-home study we will use an unobtrusive head-mounted camera to record and then later observe prosthesis/hand use during domestic tasks. In the lab study we will use a motion capture studio and video cameras to record accurate and detailed upper body motion during a series of standardized tasks. These tasks are clinically validated measures of hand / arm function functional evaluation. By recording participant performance and examining prosthesis/hand use, we expect to identify shortcomings in current terminal devices and implementations that will inform improvements to existing designs and inspire new classes of devices in the future.

## **2. KEYWORDS**

Upper Limb Prosthetics, Amputee, Assistive Technology, Motion Capture

## **3. ACCOMPLISHMENTS**

This reporting period covers the first year of the project. This portion of the project has been largely dedicated to achieving the necessary administration and equipment setup to allow us to perform the study under correct and optimal conditions.

### **What were the major goals of the project?**

The major goals of this project are to observe the upper limb manipulation techniques used by numerous upper limb prosthesis wearers and ‘healthy’ individuals (i.e. those with intact upper limbs) when achieving a variety of tasks in unstructured (in their own home) and structured (in the lab) environments. Comparing data from these two demographics over the different tasks and environment we aim to determine differences in manipulation techniques between prosthesis wearers and the healthy ‘baseline’. In particular we wish to identify the shortcomings of particular prosthetic devices or setups while looking for methods employed by prosthesis users to overcome these limitations. These

Originally the study proposed the use only of head-mounted cameras for observation. This was extended to include a motion capture system capable of accurately recording upper body motion to provide much richer movement data. The motion capture setup will be used only in the laboratory setup, due to the complexity of the measurement equipment and relatively limited capture volume.

## **What was accomplished under these goals?**

In the first year we prepared measurement equipment and the necessary protocols to enter participants into our study. In particular the following achievements have been made:

1. A kickoff meeting was held to discuss the project and timeline
2. Experimental protocols have been finalized
3. The protocol has been approved by IRBs for all institutions and the DoD. Necessary human subjects training was also completed for relevant members of the study team.
4. The head-mounted camera setup has been established (a modified GoPro Hero 3 with external pocket sized battery – giving over 6 hours of recording).
5. Software to aid analysis of the head-mounted camera data has been prototyped.
6. A Vicon optical motion capture system was selected (after reviewing several options), purchased and installed in the laboratory space of Yale University
7. Extensive setup and customization of the Vicon motion capture system has been completed. This began with on-site training from a Vicon representative but since then has led to the following:
  - a. Optimized camera placement (13 cameras in a 5x5m space) for bi-manual upper body capture when standing or seated. This also involved installing mounting rails in the laboratory
  - b. Optimized marker placement for robustness to marker occlusions (when motion capture markers are hidden from view in particular body poses). This includes flexible, wearable marker clusters and custom software methods to reconstruct occluded markers.
  - c. Custom data processing scripts to extend the functionality of Vicon software to export skeletal angles. These scripts have been written to match the guidelines of the international society of biomechanics (ISB)
8. Collection and setup of materials for the laboratory space. This includes a variable height desk (to simulate a kitchen counter or work desk) and various household items.

The setup of equipment took longer than projected in the timeline of the original proposal. This was due to the inclusion of the motion capture system. This system required development of specific skills and significant trial and error regarding camera placement, focusing and marker sets.

## **What opportunities for training and professional development has the project provided?**

The project provided the opportunity for familiarization with literature on prosthetics, motion capture and functional outcome measures. As part of this familiarization, the conference MEC (Myoelectric Controls Symposium, New Brunswick Canada) was attended by members of the project.

Technical training was completed by Dr Adam Spiers on the Vicon motion capture system. Training was also completed by Adam on protocols and policies regarding human experiments.

**How were the results disseminated to communities of interest?**

Nothing to report

**What do you plan to do during the next reporting period to accomplish the goals?**

In the next quarter we plan to recruit participants and complete the at-home and in-lab studies.

**4. IMPACT**

**What was the impact on the development of the principal discipline(s) of the project?**

While most of the efforts to date, besides IRB approvals, relate to the development of experimental protocols and frameworks/workflow systems related to the motion capture systems that we will use for the project, those efforts will be published and will enable other groups doing this kind of upper-limb motion capture to more quickly and efficiently get their experimental work going.”

**What was the impact on other disciplines?**

Nothing to report

**What was the impact on technology transfer?**

Nothing to report

**What was the impact on society beyond science and technology?**

Nothing to report

**5. CHANGES/PROBLEMS:**

**Changes in approach and reasons for change**

The original protocol was modified to include the use of an optical motion capture system. During the initial stages of the project it was determined that far greater accuracy of participant motion would be achieved with such a system, compared to the original head-mounted camera setup. This allows more detailed and objective comparison

A budget revision with an associated explanation was submitted to Elena Howell and Jason Ghanniadian of the US ARMY on 10/29/14 by Prof. Dollar and approved by Elena Howell on 11/13/2014.

**Actual or anticipated problems or delays and actions or plans to resolve them**

Training, setup and familiarization of with the motion capture system added delays to the project compared to the original forecast. However we believe the quality and impact of the resulting data will be much higher as a result of this new measurement tool and the time taken to learn

how to use it. Also, because of these efforts, we will now be able to complete the planned work faster, and we anticipate finishing the project by the originally planned target date.

**Changes that had a significant impact on expenditures**

Nothing to report

**Significant changes in use or care of human subjects, vertebrate animals, biohazards, and/or select agents**

Nothing to report

**6. PRODUCTS:**

**Publications, conference papers, and presentations**

Nothing to report

**Website(s) or other Internet site(s)**

Nothing to report

**Technologies or techniques**

We have developed marker sets and processing techniques associated with the motion capture system. These will accompany future publications as appendices.

**Inventions, patent applications, and/or licenses**

Nothing to report

**Other Products**

Nothing to report

**7. PARTICIPANTS & OTHER COLLABORATING ORGANIZATIONS**

**What individuals have worked on the project?**

Name:	Aaron Dollar
Project Role:	PI
Researcher Identifier (e.g. ORCID ID):	Aaron.dollar@yale.edu
Nearest person month worked:	1
Contribution to Project:	<b>Expert on human hand functional use and robot / prosthetic hand development. Contributed to Protocol development, measurement equipment selection and setup.</b>
Funding Support:	This award.

Name:	Linda Resnik
Project Role:	Co-PI
Researcher Identifier (e.g. ORCID ID):	linda_resnik@brown.edu
Nearest person month worked:	1.2
Contribution to Project:	<b>Expert on upper limb prosthetics and measures of upper limb functionality and rehabilitation outcomes. Contributed to protocol development.</b>
Funding Support:	This award

Name:	Adam Spiers
Project Role:	Postdoctoral Associate
Researcher Identifier (e.g. ORCID ID):	adam.spiers@yale.edu
Nearest person month worked:	12
Contribution to Project:	<b>Postdoc researcher responsible for running at-home and in-lab studies. Contributed to protocol development, IRB submission (Yale only), equipment selection, setup, customization and familiarization.</b>
Funding Support:	This award.

Name:	Kate Barnabe
Project Role:	Administrative Lead
Researcher Identifier (e.g. ORCID ID):	Kate.Barnabe@va.gov
Nearest person month worked:	1.2
Contribution to Project:	<b>Protocol development. IRB submissions (all institutions and DOD). Project administration.</b>
Funding Support:	This award



**Has there been a change in the active other support of the PD/PI(s) or senior/key personnel since the last reporting period?**

Nothing to report

**What other organizations were involved as partners?**

Nothing to report

## **8. SPECIAL REPORTING REQUIREMENTS**

A Quad Chart accompanies this report

## **9. APPENDICIES**

None

**PI:** Aaron M. Dollar

**Award Amount: \$476,646**

- Investigate prosthesis use during daily living by upper-limb amputees
- Develop task-related prosthesis usage/non-usage statistics
- Examine compensatory motions/actions
- Identify areas for device improvement and opportunities for assistive technologies

The upper-limb usage of amputee and age/gender-matched unimpaired subjects will be examined in both their home environments and a fixed laboratory environment doing a pre-described set of activities of daily living (ADLs). Their actions/movements will be recorded with head-mounted cameras (home) and motion-tracking equipment (lab).



Informal preliminary results from prior work showing amputee using a head-mounted camera utilizing the prosthesis during ADL tasks

	CY	14	15	16	17								
Activities   Milestone (m)	Q	1	2	3	4	5	6	7	8	9	10	11	12
Protocol Develop   IRB Approvals				m									
Study Equipment   Fab complete				m									
Recruit Subjects   Enrollment complete								m					
Home-based video study   Completion								m					
Lab-based study   Completion								m					
Data analysis   Final Publication													m
Estimated Budget (\$K)		\$25.6	\$247	\$95.4	\$108.6								

Updated: (10/6/15)

- ☒ Protocol Development and IRB submissions (months 1-12)
- ☒ Fabricate and Test study equipment (months 1-12)
- ☐ Subject Recruitment (months 12-24)
- ☐ Home-based video study of ADL tasks (months 12-24)
- ☐ Lab-based video study of ADL tasks (months 12-24)
- ☐ Prepare and Analyze task performance data (months 15-36)

- Award began 09/08/14
- Rebudgeted to allow purchase of motion-tracking equipment

Projected Expenditure: \$172,950  
Actual Expenditure: \$255,571.47